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Crop production in higher latitude, maritime regions

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V. Temperature dependent parameters - the growing season

General Survey

A seasonal growth cycle is characteristic of many - if not most - of the crops grown in the "higher latitudes". The duration of the period of active growth is strongly coupled to temperature. Several methods are used to express temperature in relation to the growing season, e.g.

(i) the period during which the surface layers of soil are not frozen. Physiological activity of the underground parts of the plant is either inhibited or prohibited by frozen soil, also any cultivation e.g. sowing of new season's crop, must be delayed not only until the soil layers have thawed out, but also until the soil is sufficiently dry to permit working of the soil without the risk of damaging soil structure.

(ii) the interval between the last air frost of the spring and the first of autumn i.e. a frost free season using a threshold value of air temperature of $0^{o}C$.

(iii) the period when air and or soil temperature exceeds some threshold value (usually significantly above freezing point) and linked with a temperature adequate for full functioning of the plant at some growth phase.

Topics (i) & (iii) are associated with soil conditions permitting the germination of seeds and the initiation of root activity.

Considerations under (i) are clearly of first importance in polar and arctic regions and in lower latitudes within "continental scale" land masses. In maritime areas where severe winter cold does not occur, the balance of interest shifts to (iii) whereas topics under (ii) may assume a dominant role in areas such as central Canada where a serious, perhaps irreversible, check to spring growth or to autumn ripening and conditioning arises from frost occurring within a period when mean temperature remains safely above the threshold level mentioned in (iii).

In this paper attention will be directed towards (iii) which is of major concern in maritime regions between latitudes 50° and 60° (and beyond).

The "growing season" (alternatively, especially in N American literature), the "vegetative season" is usually defined as the period when the mean daily air temperature in the standard screen - averaged over periods of 5, 10 days or a month remains above a critical threshold level. Transient excursions across the threshold may occasionally occur well outside the main period (a risk most likely associated with a 5 day (or less) averaging period) - such events are usually ignored. Period averages are then customarily struck.

The threshold temperature is usually between 5° and 7°C although 3°C and at times 0°C have been used. Particularly in Europe, a further threshold of 10°C is extensively adopted.

Some details follow:

Threshold. Value	Country/Region	Data Source
42°F ($\equiv$ 5.6°C)	UK	Meteorological Office
	Canada	(i) Canada Land Inventory Report No 3 1966
6°C ($\equiv$ 43°F)	Norway	Lufttemperatureni Norge 1861-1955 Det Norske Met Inst.

Threshold. Value	Country/Region	Data Source
45°F (= 7°C)	UK and Scandinavia	Mainly used by Foresters (Anderson and Fairbairn. Un of Ed Bull of For Dept Bull 1 1955)
40–55°F (according to crop, 42° for "general horticulture")	Canada	G McKay et al (1967) Agr Clim of Sask. Clim studies No 10 Dept Transp(Met Branch)
32° and 40°F (as bases for "growing-degree days")	Alaska	Univ of Alaska. (Inst of Agr Sciences. Tech Bull No 2 Aug 1971).

Attention will in the main be focussed upon a critical value of 42°F (= 5.6°C) or 6°C(= 43°F).

The differences in length of season due to a variation of 0.5°C in limits (viz between 6.0 and 5.6°C) were examined. As a rough "rule of thumb" it was noted that a season based on 42°F (5.6°C) was some 7–8 days longer than one based on 43°F (6.°C), in markedly maritime areas such as Northern Britain the difference increases to about 10 days.

Basic data are set out in Table 1. Further details relating to the stations mentioned are given in another paper of this series (Gloyne 1973(a)). The contrasts therein mentioned are:

as between west and east coastal regions of continental land masses

as between western coastal regions and adjacent inland areas to the east.

The shortest season (at Hebron, in E Canada) is 74 days, similar to that inland in areas further west (Churchill) but much below the 197 days at approximately the same latitude on the Pacific coast. A growing season of c.100 days can be sufficient for certain enterprises, Robertson (1953) cites vigorous growth of green vegetables at Aklavik. Barley has been grown successfully in Finland as far north

as 67°N - with a growing season of 125-135 days (Varjo 1971). Seasons of 180 days or more can be associated with an intensive and varied agriculture (e.g. Oslo) but this is certainly not a sufficient condition (e.g. Reykjavik) nor of course is a long season (Lerwick 222 days) nor a very long one (Glenamoy 318 days) necessarily consistent with such an enterprise.

Two further aspects will now be considered:

(i) the variation of growing season with altitude (an important consideration in maritime areas due to marked changes in topography typical of such areas).

(ii) the year to year variability of the length of the growing season (this behaviour is a characteristic of a number of climatological elements and can have a profound influence on the land use of an area).

The variation of the length of the "Growing Season" with increase in height of area above MSL.

It is a matter of common observation that in the higher latitude maritime regions, varieties and species of plants, their distribution, the types of land usage etc change noticeably with an increase of but a few hundreds of feet in the height above MSL. In contrast, in areas with a "continental" type climate a uniform pattern of agriculture and of land use can exist throughout an altitudinal range of many hundreds and even some thousands of feet.

One climatological expression of these contrasts is provided by the rate of reduction in the length of the growing season contingent upon the usual decrease in mean temperature with increasing altitude.

The topic to be examined is clarified in Fig 1 from which it can be seen that provided

(i) the curve of mean temperature intercepts the threshold temperature;

then (ii) in any given area, the length of the season (L) will decrease with increase of height due to the associated decrease in mean temperature (ΔT);

(iii) the steeper the temperature curve i.e. the greater the annual range of temperature, the less rapidly will the intercept L decrease for a given

value of ΔT (i.e. for a given increase in ht above MSL);

(iv) the possibility of an acceptable linear relationship between L and height (effected through ΔT) requires that the portion of the temperature-time curve is approximately linear; alternatively, a linear relationship cannot be expected if either the annual maximum or annual minimum is close to $42^{\circ}F$.

Gloyne (1958) has shown that in N England and S Scotland the length of the season L (in days) is related to the increase in height H (in hundreds of feet) by the equation;

$L = 245 - 4.0H$ (1 day per 25 feet)

in the English Midlands it is

$L = 264 - 4.7H$ (1 day per 21 feet)

on the coastal areas of West Wales

$L = 305 - 5.8H$ (1 day per 17 feet)

(if H is in 100's of metres the three coefficients are respectively 13.1, 15.4, 19.0)

An examination of the variations in several regions of Norway revealed variations per 100m increase in height of:

Southern and South Western Norway (ignoring the immediate coastal strip)	10 days/100m
Central and Eastern Norway	6–7 days/100m

Langlet (1936) suggested that, in Norway, the growing season decreases by about 5 days per 100m.

Patterson (1967) in a more detailed study found that the reduction in length of growing season with altitude is "not linear but is faster at low levels than at high levels", and states (in terms of days/100m height increase)

Ht Zone	Days/100m
0 – 100(m)	12 – 13
100 – 300	6 – 7
300 – 500	5
500 – 600	4

It has also been noted, in this current study, that a figure similar to that for coastal regions is valid for areas bordering inland waters (fjords.).

For inland ("continental") regions Conrad (1946) quotes a relationship for Switzerland of

$L = 268 - 7H$ (H is 100s of metres)

Manley has written extensively on this topic (e.g. Manley 1944) and notes that:

in N England there is a decrease of 10 days per 250 feet (75m) increase in height.

in New England States (USA): decrease of 10 days per 520 feet (156m).

in Berne (Switzerland: decrease of 10 days per 420 feet (126m).

Elsewhere Manley (1970) states that (in N England and S Scotland) a rate of decrease of about 14 days per 100m "is more rapid than in any other temperate land for which we have data". An analysis of some data for Iceland (Eythorsson J and Sigtryggson H 1971, and Einarsson 1973) indicated a rate of reduction of the growing season in SW Iceland of even more viz about 17 days per 100m.

In summary then, there can be little doubt that in maritime Britain and in some other geographically similar regions the length of the growing season shrinks with increase in height at a rate which is quite exceptional and very much greater than in continental inland regions. That this has important implications for questions of land use and agriculture is obvious.

Year to year variability of the growing season

The economics of production are closely linked with the reliability and predictability of inputs: amongst these climate and weather are important in agriculture and the length of the growing season is a significant component in the weather inputs.

Some data on the year-to-year variability of the growing season will now be discussed drawing mainly upon:

(a) extracts from a detailed study of the situation at Eskdalemuir Observatory (Gloyne 1973(b)).

(b) some data for a selection of stations in Norway.

Pertinent data of Eskdalemuir on a decadal basis are set out in Table 2. Amongst the facts revealed are:

(i) a considerable, up to 5 days, variation in decadal mean values of the three parameters viz. dates of beginning and end of the season, and in the length of the season. The within-decade variation - as evidenced by the standard deviation - is several multiples of the between-decade variation.

(ii) with but one exception (viz the 'decade' 1914-20) the variability of the date of beginning of the season is greater than that for the end of season.

Also from Table 2, it is apparent that the mean data (D_1) of beginning of the season has been some 9 days earlier in 1941-70 than in the earlier period (1914-40): the mean data (D_2) of end of season has been delayed some 4 days: in consequence the length of season (L) has, on average, been exteneded by some 13 days.

Scrutiny of the detailed run of the plot of L showed that the length of the season ranged between wider limits (generally 182 to 250 days) in the period 1938-1961 than either before or subsequent to those dates.

A measure of year to year variability is afforded by the "mean deviation" between successive seasons (i.e. average difference, irrespective of sign). The results for three stated periods are:

1914-1935	(22 differences)	mean deviation:	17.7 days
1936-1961	(26 ")	" " :	27.4 "
1962-1970	(8 ")	" " :	13.3 "

A further expression of year to year variability is provided by examining the number of "turning points" in the plot of L against year. The number of such points (viz 40) for the whole period differs negligibly from the expected value of 39. Accordingly there is no tendency for years to be grouped in ascending or descending sequences; equally there is no evidence of any tendency for a compensating effect between successive years.

A comparison between Eskdalemuir and some Norwegian stations is given in Table 3.

At Bergen the "season" is similar in timing and duration to that at Eskdalemuir, otherwise - and especially in East Norway - the growing season is shorter (less than 6 months) starting later and finishing earlier. From the limited example examined, and Bergen apart, the commencing date is less variable in Norway than at Eskdalemuir in contrast to the date of end of season. The variability of length of season tends to be rather less in Norway than at Eskdalemuir but by no means as markedly so as the more "continental" character of eastern Norway might suggest.

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Table 1. Data relating to the Growing Season: averages for periods stated

D_1 = date (and day of year) of beginning of season

D_2 = " (" " " ") " end " "

L = length of season (in days)

Place	Threshold Temp	Period	D_1	D_2	L
Aklavik (68°14N. 135°00W)	42°F	-	Jun 2 (153)	Sep 9 (252)	99
Tromso (No 2)	42	1931–60	May 21 (141)	Oct 2 (275)	134
Karasjok (No 3)	6°C (43°F)	1901–30	May 29 (149)	Sep 14 (257)	108
Sodankyla (No 4)	42	1931–60	May 18 (138)	Sep 20 (263)	125
Reykjavik (No 5)	42	1931–60	May 3 (123)	Oct 12 (285)	162
Trondheim (No 6)	42	1931–60	Apr 28 (118)	Oct 14 (287)	169
Sitka (No 7)	42	-	Apr 20 (110)	Nov 3 (307)	197
Fort Nelson (No 8)	42	1931–60	Apr 28 (118)	Sep 30 (273)	155
Churchill (No 9)	42	"	Jun 12 (163)	Sep 16 (259)	96
Hebron (No 10)	42	1883–1918	Jun 25 (176)	Sep 7 (250)	74
Lerwick (No 11)	42	1931–60	Apr 15 (105)	Nov 23 (327)	222
Bergen (No 12)	42	"	Apr 12 (102)	Nov 16 (320)	218
Oslo (No 13)	42	"	Apr 18 (108)	Oct 19 (292)	184
Stockholm (No 14)	42	"	Apr 20 (110)	Oct 28 (301)	191
Helsinki (No 15)	42	"	Apr 30 (120)	Oct 12 (285)	165
Okhotsk (No 16)	42	"	Jun 10 (161)	Sep 24 (267)	106
Prince Rupert (No 17)	42	"	Apr 5 (95)	Oct 31 (304)	229
Grand Prairie (No 18)	42	1921–50	Apr 26 (116)	Oct 10 (283)	167
Hopedale (No 19)	42	1941–50	Jun 10 (161)	Sep 30 (273)	112
Glenamoy (No 20)	42	1959–68	Feb 21 (52)	Dec 26 (360)	308
Dumfries (No 21)	42	1931–60	Mar 26 (85)	Nov 15 (319)	234
Eskdalemuir (No 22)	42	"	Apr 8 (98)	Nov 5 (309)	211
Edinburgh (No 23)	42	"	Mar 19 (78)	Nov 26 (330)	252
Copenhagen (No 24)	42	"	Apr 9 (99)	Nov 14 (318)	219
Usk Kamchetsk (No 25)	42	1914–18, 24	Jun 4 (155)	Oct 1 (274)	119
Petroparlorsk (No 26)	42	1846–72 1896–1928	Jun 1 (152)	Oct 10 (283)	131
Kew (No 27)	42	1931–60	Mar 5 (64)	Dec 10 (344)	282

Table 2. "Growing Season" at Eskdalemuir 1914–1970.
Decadal and period values of mean date of beginning of season (D_1); of end of season (D_2) and length of season (L); together with range and standard deviation.

Period	D_1			D_2			L		
	Mean value	Range	SD	Mean value	Range	SD	Mean value	Range	SD
1914–20	19/4	8/4–4/5	7	4/11	21/10–22/11	13	199	184–217	12
1921–30	21/4	3/4–4/5	10	30/10	17/10–15/11	8	192	173–217	12
1931–40	11/4	3/3–27/4	16	3/11	19/10–22/11	11	206	175–264	25
1941–50	6/4	11/3 29/4	15	4/11	23/10–17/11	8	213	184–243	19
1951–60	8/4	16/3–30/4	18	9/11	19/10–19/11	9	215	187–248	19
1961–70	10/4	1/3–24/4	15	4/11	27/10–14/11	6	209	195–250	17
1914–1940	17/4	3/3–4/5	13	2/11	17/10–22/11	11	199	173–264	19
1941–1970	8/4	1/3 30/4	16	6/11	19/10 19/11	8	212	184–250	19

Table 3. Mean date M (day of year) of beginning (D_1) and end (D_2) of growing season, and length (L) of season at Eskdalemuir and selected station in Norway for two periods together with standard deviation (σ).

Bergen	60° 24'N	5° 69'E	Oslo	59° 56'N	10° 44'
Leikanger	61° 11'N	6° 52'E	Lillehamer	61° 05'N	10° 29'
Kvamsgogen	60° 24'N	5° 55'E	Ås	59° 40'N	10° 47'

Place and Height above MSL	D_1				D_2				L			
	1943–70		1961–70		1943–70		1961–70		1943–70		1961–70	
	M	σ	M	σ	M	σ	M	σ	M	σ	M	σ
Eskdalemuir (242 m)	98	16	100	15	310	8	308	6	212	19	209	17
Bergen (43 m)	97	18	112	10	308	9	303	5	286	22	191	11
Leikanger (222 m)	102	13	129	7	291	12	295	8	186	19	185	12
Kvamsgogen (555 m)	–	–	141	8	–	–	280	12	–	–	138	14
Lillehamer (190 m)	–	–	124	7	–	–	277	9	–	–	153	15
Oslo (94 m)	–	–	115	8	–	–	287	9	–	–	172	9
Ås (95 m)	110	10	118	10	285	11	288	11	174	15	170	14

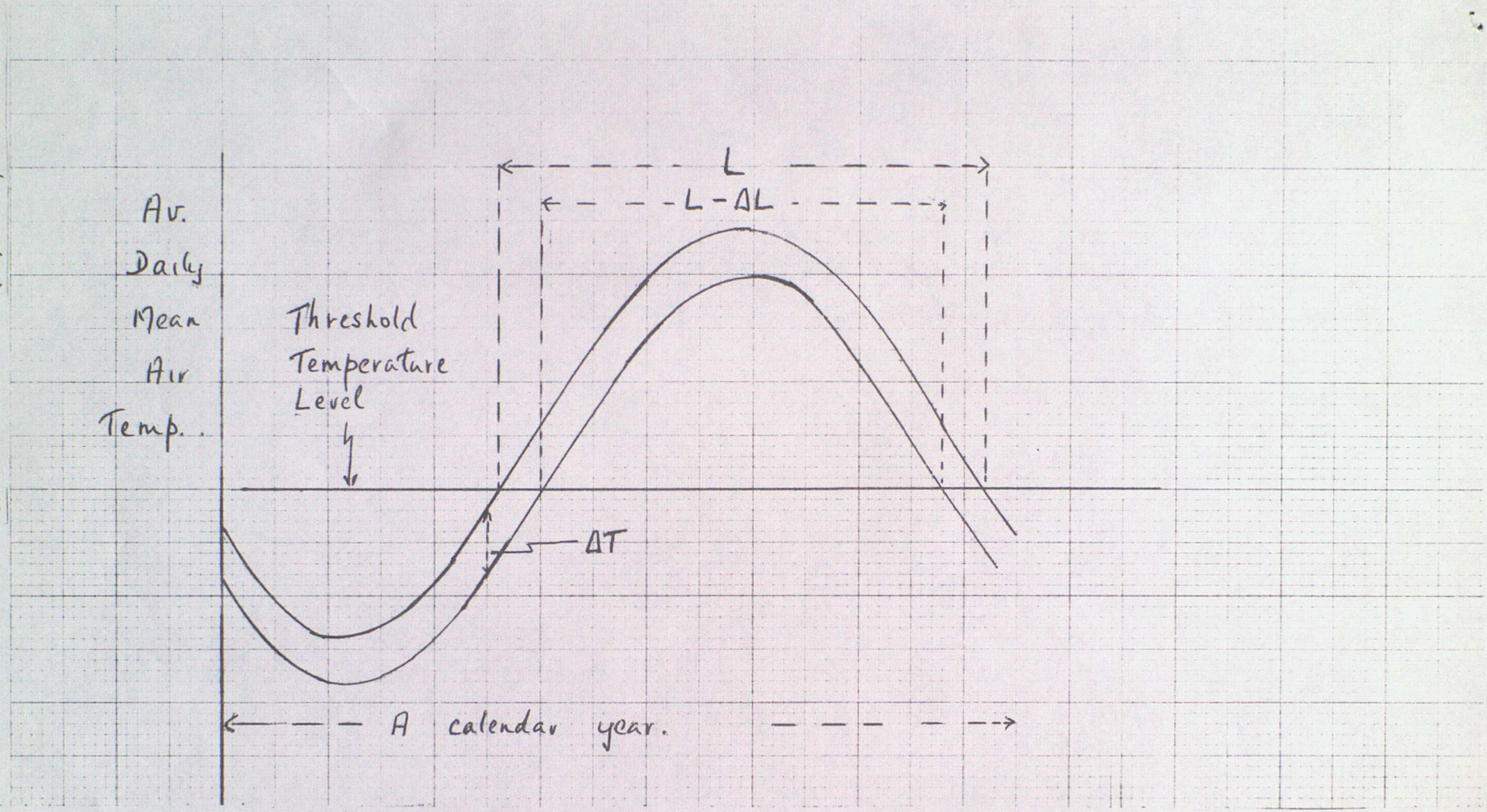

Fig 1. Schematic diagram to show reduction (Δ L) in length of growing season (L) with height-dependent reduction (ΔT) in mean air temperature.